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Hisamitsu ARAI
(seal)

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Title of the Invention: LIGHT EMITTING DIODE AND DISPLAY DEVICE USING THE SAME

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Inventor:

Address: c/o Nichia Chemical Industries, Ltd., 491-100, Oka, Kaminakacho, Anan-shi, Tokushima, Japan
Name: Yoshinori SHIMIZU

Inventor:

Address: c/o Nichia Chemical Industries, Ltd., 491-100, Oka, Kaminakacho, Anan-shi, Tokushima, Japan
Name: Kensho SAKANO

Applicant:

Identification No.: 000226057
Zip Code: 774
Address: 491-100, Oka, Kaminakacho, Anan-shi, Tokushima, Japan
Name: Nichia Chemical Industries, Ltd.
Representative: Eiji OGAWA
Telephone No.: 0884-22-2311

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[Document Name] Specification

[Title of the Invention] LIGHT EMITTING DIODE AND DISPLAY DEVICE USING THE SAME

[What is claimed is]

[Claim 1] A light emitting diode comprising a LED chip using a gallium nitride compound semiconductor as a light emitting layer and a phosphor which absorbs at least a part of light emitted by the LED chip to emit light by converting the wavelength, wherein

a main peak of the emission spectrum of the LED chip has an emission wavelength within the range from 400nm to 530nm and the phosphor is represented by $RE_3(Al,Ga)_5O_{12}$:Ce, where RE is at least one selected from Y, Gd and Sm.

[Claim 2] A light emitting diode comprising a LED chip placed in a cup of a mount lead, an inner lead electrically connected with the LED chip with a conductive wire, a coating material filling the cup and a molding material covering at least part of the coating material, the LED chip, the conductive wire, the mount lead and the inner lead, wherein

the LED chip is a gallium nitride compound semiconductor and the coating material is a translucent resin containing a phosphor of $RE_3(Al,Ga)_5O_{12}$:Ce where RE is at least one selected from Y, Gd and Sm.

[Claim 3] A light emitting diode according to claim 1 or 2, wherein the composition of the phosphor is represented by the following general formula:

$(Y_{1-p-q-r}Gd_pCe_qSm_r)_3(Al_yGa_{1-y})_5O_{12}$

where $0 \le p \le 0.8$

$0.003 \le q \le 0.2$

$0.0003 \le r \le 0.08$

$0 \le s \le 1$

[Claim 4] A LED display device comprising a LED display provided with the light emitting diodes of claim 2 in the matrix form, and a drive circuit electrically connected with the LED display.

[Detailed Description of the Invention]

[0001]

[Industrial Utilization Field]

The present invention relates to a light emitting diode which is used in LED display, back light source, signal, illuminating switch, indicator, etc. More particularly, it relates to a light emitting diode having a phosphor, which converts light emitted by a LED chip that is a light emitting component and emits light, and providing high luminance and high efficiency regardless of the operating environment, and a display device using the same.

[0002]

[Prior Art]

A light emitting diode (hereinafter referred to as LED) is compact and emits light of clear color with high efficiency. It is also free from such a trouble as burn-out because it is a

semiconductor element. It has an excellent initial drive characteristic and such an advantage as durability to endure vibration and repetitive ON/OFF operations. Thus it has been used in such applications as various indicators and various light sources. Recently light emitting diodes for RGB (red, green and blue) colors having ultra-high luminance and high efficiency have been developed. Accordingly, LED displays using the three primary colors of RGB have been greatly advancing by making most of the advantages such as low power consumption, long life and light weight.

[0003]

The light emitting diode can emit light of various wavelengths ranging from ultra violet to infrared, depending on the semiconductor material and conditions to form a light emitting layer to be used. It also has favorable emission spectrum to generate monochromatic light.

[0004]

Although because the light emitting diode has favorable emission spectrum to generate monochromatic light, making a light source for white light requires it to arrange the LED chips which are capable of emitting light of RGB colors closely to each other while diffusing and mixing the light emitted by them. Although these light emitting diodes are effective as light emitting devices for emitting various colors freely, a set of red green and blue light emitting diodes or a set of blur-green and yellow light

emitting diodes must be used even when generating white light only. A LED chip is a semiconductor and still includes considerable variations in the color tone and luminance. Also in case the LED chips which are semiconductor light emitting component are made from different materials, different LED chips require different drive voltages which must be supplied from different power sources provided separately. Therefore, white light must be generated by adjusting the current for each semiconductor. Similarly, color tone is subject to variation due to the difference in temperature characteristics and chronological changes, because the LED chips are semiconductor light emitting elements. Further, uneven color may result unless the light rays emitted by the LED chips are mixed evenly.

[0005]

Thus the present applicant previously developed light emitting diodes which convert the color of light emitted by a LED chip by means of a fluorescent material disclosed in Japanese Patent Kokai Nos. 5-152609 and 7-99345. By using these light emitting diodes, light of other colors such as white color can be emitted by using a LED chip of one type.

[0006]

Specifically, a LED chip having a large energy band gap of light emitting layer is arranged in a cup provided at the tip of lead frame. The LED chip is electrically connected to a metal stem or metal post where the LED chips are provided. Then a

fluorescent material which absorbs the light emitted by the LED chip and converts the wavelength is contained in a resin mold which covers the LED chip.

[0007]

As a light emitting diode which converts the wavelength of light emitted by a LED chip, such a light emitting diode can be used which can emit white light by mixing light emitted by a blue light emitting diode and yellow light emitted by a fluorescent material which absorbs the light emitted by the blue light emitting diode. These light emitting diodes can emit light with sufficient luminance even when used to emit white light.

[0008]

[Problems to be solved by the Invention]

There are various fluorescent materials such as fluorescent dye, fluorescent pigment and organic or inorganic compounds which are excited by light emitted by a light emitting diode. Also there are fluorescent materials which convert light of shorter wavelength emitted by a light emitting element into light of longer wavelength and those which convert light of longer wavelength emitted by a light emitting element into light of shorter wavelength.

[0009]

However, efficiency of conversion of long-wavelength light into short-wavelength light is extremely low and is not practical. A fluorescent material arranged close to a LED chip is

exposed to light of a radiation intensity as high as about 30 to 40 times that of sunlight. Especially when a LED chip as a light emitting component is made by using a semiconductor having a high energy band gap to improve the conversion efficiency of the fluorescent material and reduce the quantity of the fluorescent material consumed, light energy inevitably increases even though the light emitted by the LED chip falls within visible light range. In this case, when the emission intensity is increased and used for a long period of time, the fluorescent material can deteriorate. There is such a case as the color tone changes as the fluorescent material deteriorates or such a case as the fluorescent material is blackened resulting in lowered efficiency of extracting light. Similarly, the fluorescent material provided in the vicinity of the LED chip is exposed to a high temperature such as rising temperature of the LED chip and from the external environment. Further, although a light emitting diode is usually sealed in a resin molding, it is impossible to completely prevent the entry of moisture from the outside or to completely remove moisture which was contained during production. In the case of some fluorescent materials, such moisture accelerates the deterioration of the fluorescent material due to the high-energy radiation or heat transmitted from the light emitting component. When it comes to an organic dye of ionic property, direct current electric field in the vicinity of the chip may cause electrophoresis, resulting in a change in the color tone. Therefore, the present invention

is intended to solve the problems described above and provide a light emitting diode which is subject only to extremely low degrees of deterioration in light emission efficiency and color shift over a long period of time with high luminance.

[0010]

[Means for Solving the Problems]

The light emitting diode of claim 1 of the present invention comprises a LED chip comprising a light emitting layer of gallium nitride semiconductors and a phosphor which absorbs at least a part of the light emitted by the LED chip to emit light by converting the wavelength. A main peak of the emission spectrum of the LED chip has an emission wavelength within the range from 400nm to 530nm and and the phosphor is represented by $RE_3(Al,Ga)_5O_{12}$:Ce, where Re is at least one selected from Y,Gd and Sm.

[0011]

The light emitting diode of claim 2 of the present invention comprises a LED chip placed in a cup of a mount lead, an inner lead electrically connected with the LED chip by means of a conductive wire, a coating material filling the cup and a molding material covering at least part of the coating material, the LED chip, the conductive wire, the mount lead and the inner lead. With respect to this light emitting diode, the LED chip is a gallium nitride compound semiconductor and the coating material is a translucent resin containing a phosphor of $RE_3(Al, Ga)5O_{12}$:Ce,

where RE is at least one selected from Y, Gd and Sm.

[0012]

Further, with respect to the light emitting diode of claim 3 of the present invention, the phosphor is represented by the following general formula:

$(Y_{1-p-q-r}Gd_pCe_qSm_r)_3(Al_{1-s}Ga_s)_5O_{12}$

where $0 \le p \le 0.8$

$0.003 \le q \le 0.2$

$0.0003 \le r \le 0.08$

$0 \le s \le 1$

[0013]

Also the display device of claim 4 of the present invention comprises a LED display provided with the light emitting diodes of claim 2 in the matrix form, and a drive circuit electrically connected with the LED display.

[0014]

[Mode for carrying out the Invention]

The present inventors have found, as a result of various experiments, that it is made possible to prevent the decrease in emission efficiency and color shift through operation with a high luminance over a long period of time by selecting a particular semiconductor and a fluorescent material in a light emitting diode which uses a phosphor to convert the color of light emitted by a LED chip having a relatively high radiation energy in visible region, and have achieved the present invention.

[0015]

The phosphor used in the light emitting diode must satisfy the following requirements:

1. Excellent resistance against light, particularly durability to endure light of a radiation intensity as high as about 30 to 40 times that of sun light, because the fluorescent material is exposed to intense radiation from a tiny region such as a semiconductor light emitting element.

2. Capability to emit light in blue region, not ultra violet, because mixing of colors with the light emitting elements is used.

3. Capability to emit light from green to red regions in consideration of mixing with blue light.

4. Good temperature characteristic suitable for location in the vicinity of the light emitting component.

5. Capability to continuously change the color tone in terms of the proportion of composition or ratio of mixing a plurality of fluorescent materials.

6. Weatherability for the operating environment of the light emitting diode.

[0016]

As materials that satisfy the above requirements, the present invention uses a gallium nitride compound semiconductor element having high-energy band gap in the light emitting layer as the light emitting diode, and $RE_3(Al, Ga)5O_{12}$:Ce fluorescent

material as the phosphor, in combination. This makes it possible to make a light emitting diode which experiences color shift of emitted light and a decrease in luminance of the emitted light, both of very low degrees, even when irradiated with high-energy radiation in the visible light region emitted by the light emitting component in the vicinity thereof over a long period of time.

[0017]

As one embodiment of the light emitting, a chip type LED is shown in Fig. 2. A LED chip 202 employing gallium nitrate semiconductor is fixed in the casing 204 of the chip type LED by means of an epoxy resin or the like. Electrodes of the LED chip 202 and electrodes 205 provided on the casing are electrically connected by means of gold wires which are conductive wires 203. The epoxy resin with $RE_3(Al,Ga)_5O_{12}$:Ce fluorescent material mixed and dispersed therein is applied uniformly as a molding material 201 for the protection of the LED chip and the conductive wires from extraneous stresses. The LED chip 202 is caused to emit light by supplying electric power to the light emitting diode. By mixing light emitted by the LED chip 202 and light emitted by the phosphor excited by the light emitted by the LED chip, the light emitting diode can emit light of white color. Constituents of the present invention will now be described below.

[0018]

(Fluorescent material)

The phosphor used in the light emitting diode of this

invention is a phosphor which emits light when excited by visible light or ultra violet light emitted by the semiconductor light emitting component. Specifically, the phosphor is $RE_3(Al,Ga)_5O_{12}$:Ce (where RE is at least one selected from Y, Gd, and Sm). In case the light emitted by the LED chip employing the gallium nitride compound semiconductor and the light emitted by the phosphor having yellow body color are in the relation of complementary colors, display with white color can be achieved by mixing light emitted by the LED chip and the light emitted by the phosphor. Therefore, it is necessary that light emitted by the LED chip and the light emitted by the phosphor transmit through the molding material to the outside of the light emitting diode. Thus the light emitting diode may also be made in such a construction as the LED chip is enclosed in a bulk layer of phosphor and the phosphor is provided with one or two or more apertures which allow the light from the LED chip to pass. Such a construction may also be employed as the phosphor in the form of powder is contained in a resin or glass which is formed into a thin layer enough to allow the light from the LED chip to pass through. It is made possible to provide a desired color tone such as white and the color of incandescent lamp light, by controlling the proportions of the phosphor and the resin and the amounts of coating or filling, and by selecting the wavelength of light emitted by he light emitting component.

[0019]

Distribution of the phosphor concentration has influence also on the color mixing and durability. That is, when the concentration of phosphor increases from the surface of the coating or molding where the phosphor is contained toward the LED chip, it is less likely to be affected by extraneous moisture thereby making it easier to suppress the deterioration due to moisture. On the other hand, when the concentration of phosphor increases from the LED chip toward the surface of the molding, it becomes more likely to be affected by extraneous moisture, but less likely to be affected by the heat and radiation from the LED chip, thus making it possible to suppress the deterioration of the phosphor. Such distributions of the phosphor concentration can be achieved by selecting or controlling the material which includes the phosphor, forming temperature and viscosity, and the configuration and particle distribution of the phosphor. Therefore, various distributions of the phosphor concentration can be selected according to the operating conditions.

[0020]

By using the phosphor of the present invention, the light emitting diode can be given enough light resistance for high-efficient operation even when arranged adjacent to or in the vicinity of the LED chip with radiation illuminance (Ee) in a range from 3 Wcm^{-2} up to 10 Wcm^{-2}.

[0021]

The phosphor used in the present invention is, because

of garnet structure, resistant to heat, light and moisture, and is capable of absorbing excitation light having a peak at a wavelength near 450 nm. It also emits light of broad spectrum having a peak near 530 nm tailing out to 700 nm. Moreover, wavelength of the emitted light is shifted to a shorter wavelength by substituting part of Al of the composition with Ga, and the wavelength of the emitted light can be shifted to a longer wavelength by substituting part of Y of the composition with Gd. In this way, the light color of emission can be changed continuously by changing the composition. Thus the phosphor has ideal characteristics for converting blue light of nitride semiconductor into white light, such as the capability of continuously changing the intensity of light of long wavelengths in terms of the proportion of Gd.

[0022]

The efficiency of light emission can be further improved by making a light emitting diode comprising a LED chip employing gallium nitride semiconductor and a phosphor made by adding rare earth element samarium (Sm) in yttrium-aluminum-garnet fluorescent materials (YAG) activated with cerium.

[0023]

Material for making such a phosphor is made by using oxides of Y, Gd, Ce, Sm, Al and Ga or compounds which can be easily converted into these oxides at high temperatures, and mixing these materials well in stoichiometrical proportions. Otherwise, a mixture material is obtained by dissolving rare earth elements Y,

Gd, Ce and Sm in stoichiometrical proportions in an acid, coprecipitating the solution with oxalic acid and firing the coprecipitate to obtain an oxide of the coprecipitate, which is then mixed with aluminum oxide and gallium oxide. This mixture is mixed with an appropriate quantity of a fluoride such as ammonium fluoride used as a flux, and fired in a crucible at a temperature from 1350 to 1450 °C in air for 2 to 5 hours. Then the fired material is ground by ball mill in water, washed, separated, dried and sieved thereby to obtain the desired material.

[0024]

The phosphor having the composition of $(Y_{1-p-q-r}Gd_pCe_qSm_r)_3Al_5O_{12}$ can emit light of long wavelengths of 460 nm and longer with higher efficiency upon excitation, because Gd is contained in the crystal. When the content of gadolinium is increased, peak wavelength of emission shifts from 530 nm to a longer wavelength up to 570 nm, while the entire emission spectrum shifts to longer wavelengths. When light of stronger red color is needed, it can be achieved by increasing the amount of Gd added for substitution. When the content of gadolinium is increased, luminance of photoluminescence with blue light gradually decreases. Therefore, value of p is preferably 0.8 or lower, or more preferably 0.7 or lower. Further more preferably it is 0.6 or lower.

[0025]

The fluorescent material having the composition of $(Y_{1-p-q-r}Gd_pCe_qSm_r)_3Al_5O_{12}$ containing Sm has less dependence on

temperature regardless of the increased content of Gd. The phosphor, when Sm is contained as described above, provides greatly improved emission luminance at higher temperatures. Extent of the improvement increases as the Gd content is increased. That is, it was found that greater improvement of temperature characteristic by the addition of Sm can be achieved when Gd content is increased to give red color to the color tone of light emitted by the phosphor. The temperature characteristic mentioned here is measured in terms of the ratio (%) of emission luminance of the fluorescent material at a high temperature (200 °C) relative to the emission luminance of exciting blue light of wavelength 450 nm at the normal temperature (25 °C).

[0026]

Content of Sm is preferably in a range of $0.0003 \le r \le 0.08$ to give temperature characteristic of 60% or higher. Value of r below this range leads to less effect of improving the temperature characteristic. When the value of r is above this range, on the contrary, the temperature characteristic deteriorates. Range of $0.0007 \le r \le 0.02$ where temperature characteristic becomes 80% or higher is the most desirable.

[0027]

When Ce content is within the range $0.003 \le q \le 0.2$, relative emission luminance becomes 70% or higher. When the value of q is 0.003 or lower, luminance decreases because the number of excited emission centers of photoluminescence due to Ce decreases and, when

the q is greater than 0.2, density quenching occurs.

[0028]

For the phosphor used in the light emitting diode of the present invention, a mixture of two or more kinds of phosphors having compositions of $RE_3(Al,Ga)_5O_{12}$:Ce may also be used. That is, RGB components can be increased by mixing two or more kinds of phosphors having compositions of $RE_3(Al,Ga)_5O_{12}$:Ce having different contents of Al, Ga, Y and Gs or Sm. This, with the addition of a color filter, can also be used for a full-color liquid crystal display device.

[0029]

(LED chips 102, 202, 702)

The LED chip used in the light emitting diode of the present invention is a nitride compound semiconductor capable of efficiently exciting the $RE_3(Al,Ga)_5O_{12}$:Ce fluorescent material. The LED chip which is the light emitting component is made by forming a light emitting layer of semiconductor such as InGaN on a substrate in the MOCVD process. The semiconductor structure may be homostructure, heterostructure or double-heterostructure which have MIS junction, PIN junction or PN junction. Various wavelengths of emission can be selected depending on the material of the semiconductor layer and the crystalinity thereof. It may also be made in a single quantum well structure or multiple quantum well structure where a semiconductor activation layer is formed in a thin film where quantum effect can occur.

[0030]

When a gallium nitride compound semiconductor is used, sapphire, spinnel, SiC, Si, ZnO or the like is used as the semiconductor substrate. Use of sapphire substrate is preferable in order to form gallium nitride of good crystalinity. A buffer layer of GaN, AlN, etc. is formed on the sapphire substrate, and gallium nitride semiconductor having PN junction is formed thereon. The gallium nitride semiconductor has N type conductivity under the condition of not doped with any impurity. In order to form an N type gallium nitride semiconductor having desired properties such as improved light emission efficiency, it is preferably doped with N type dopant such as Si, Ge, Se, Te, and C. In order to form a P type gallium nitride semiconductor, on the other hand, it is preferably doped with P type dopant such as Zn, Mg, Be, Ca, Sr and Ba. Because it is difficult to turn a gallium nitride compound semiconductor to P type simply by doping a P type dopant, it is preferable to anneal the gallium nitride compound semiconductor doped with P type dopant in such process as heating in a furnace, irradiation with low-speed electron beam, plasma irradiation, etc., thereby to turn it to P type. After exposing the surfaces of P type and N type semiconductor layers by etching or other process, electrodes of the desired shapes are formed on the semiconductor layers by sputtering or vapor deposition.

[0031]

Then the semiconductor wafer which has been formed is cut into pieces by means of a dicing saw which has a rotating blade

having diamond cutting edge, or separated by an external force after cutting grooves (half-cut) which have width greater than the blade edge width. Or otherwise, the wafer is cut into chips by scribing grid pattern of extremely fine lines on the semiconductor wafer by means of a scriber having a diamond stylus which makes straight reciprocal movement. Thus the LED chips of gallium nitride compound semiconductor can be made.

[0032]

In order to emit white light with the light emitting diode of the present invention, wavelength of light emitted by the light emitting component is preferably from 400 nm to 530 nm inclusive in consideration of the complementary color relationship with the phosphor and deterioration of resin, and more preferably from 420 nm to 490 nm inclusive. It is further more preferable that the wavelength be from 450 nm to 475 nm inclusive, so as to increase the emission efficiency of the LED chip and the phosphor, respectively. Emission spectrum of the white light emitting diode of the present invention is shown in Fig. 3, which is the spectrum of photoluminescence having a peak at a wavelength near 570 nm, generated by excitation by light emitted from a LED chip having a peak at a wavelength near 450 nm..

[0033]

(Conductive wires 103, 203)

The conductive wires 103, 203 should have good electric conductivity, good thermal conductivity and good mechanical

connection with the electrodes of the LED chips 102, 202. Thermal conductivity is preferably 0.01 cal/cm^2/cm/°C or higher, and more preferably 0.5 cal/cm2/cm/°C or higher. For workability and other reasons, the diameter of the conductive wire is preferably from Φ10 μm to Φ45 μm inclusive. The conductive wire may specifically be a metal such as gold, silver, platinum and aluminum or an alloy thereof. Such a conductive wire can be easily connected to the electrodes of the LED chips, the inner lead and the mount lead by means of a wire bonding device.

[0034]

(Mount lead 105)

The mount lead 105 is used for mounting of the LED chip 102, and suffices to have a size enough to load with a die bonding equipment or the like. In case a plurality of LED chips are installed and the mount lead is used as common electrode of the LED chips, sufficient electric conductivity and good connecting characteristic with the bonding wires and the like are required. When the LED chip is installed in the cup of the mount lead and the cup is filled with the fluorescent material, erroneous illumination due to light from other light emitting diode mounted nearby can be prevented.

[0035]

Bonding of the LED chip 102 and the mount lead 105 with the cup can be achieved by means of a thermoplastic resin. Specifically, epoxy resin, acrylic resin and imide resin can be

used. When bonding a face-down LED chip and the mount lead and, at the same time, electrically connecting them, Ag paste, carbon paste, metallic bump or the like can be used. Further, in order to improve the efficiency of light utilization of the light emitting diode, surface of the mount lead whereon the LED chip is mounted may be mirror-polished to give reflecting function to the surface. In this case, the surface roughness is preferably from 0.1S to 0.8S inclusive. Electric resistance of the mount lead is preferably within 300 $\mu\Omega$-cm and more preferably within 3 $\mu\Omega$-cm. When mounting a plurality of LED chips on the mount lead, the LED chips generate significant amount of heat and therefore high thermal conductivity is required. Specifically, the thermal conductivity is preferably 0.01 cal/cm^2/cm/°C or higher, and more preferably 0.5 cal/cm2/cm/°C or higher. Materials which satisfy these requirements include steel, copper, copper-clad steel, copper-clad tin and metallized ceramics.

[0036]

(Inner lead 106)

The inner lead 106 provides connection between the LED chip 102 mounted on the mount lead 105 and the conductive wire 103. When mounting a plurality of LED chips on the mount lead, it is necessary to employ such a construction that the conductive wires can be arranged so as not to touch each other. Specifically, contact of the conductive wires with each other which connect the inner leads that are more distant from the mount lead can be

prevented by increasing the area of the end face where the inner lead is wire-bonded as the distance from the mount lead increases. Surface roughness of the end face connecting with the conductive wire is preferably from 1.6S to 10S inclusive in consideration of close contact. In order to form the tip of the inner lead in a desired shape, the shape may be formed by punching the lead frame with a die in advance, or by grinding off a part of inner leads at the top after forming all inner leads. Further, after forming by punching the inner leads, desired end face area and height can be formed simultaneously by applying pressure in the direction of end face.

[0037]

The inner lead is required to have good connectivity with the bonding wires which are conductive wires and good electrical conductivity. Specifically, the electric resistance is preferably within 300 $\mu\Omega$-cm and more preferably within 3 $\mu\Omega$-cm. Materials which satisfy these requirements include iron, copper, copper containing iron, copper containing tin, copper-, gold- or silver-plated aluminum, iron or copper.

[0038]

(Coating material 101)

The coating material 101 used in the present invention is provided in the cup of the mount lead in addition to the molding material 104, and includes the phosphor which converts the light emitted by the LED chip. As the coating material, transparent

materials of excellent weatherability such as epoxy resin, urea resin and silicon and glass are preferably employed. A dispersant may be used together with the phosphor. As the dispersant, barium titanate, titanium oxide, aluminum oxide, silicon dioxide and the like are preferably used.

[0039]

(Molding material 104)

The molding 104 may be provided in order to protect the LED chip 102, the conductive wire 103 and the coating material 101 which includes phosphor from external disturbance, depending on the application of the light emitting diode. The molding material can be generally made of a resin. While the angle of view can be increased by containing the phosphor, the angle of view can be further increased by adding a dispersant in the resin molding thereby making the directivity of the emission from the LED chip 102 dull. Further, the molding material 104 may be formed in a desired shape having the function of lens to focus or diffuse the light emitted by the LED chip. Therefore, the molding material 104 may be made in a structure of multiple layers laminated. Specifically, it may be a convex lens or a concave lens, and may have an elliptic shape when viewed in the direction of optical axis, or a combination of these. As the molding material 104, transparent materials of excellent weatherability such as epoxy resin, urea resin and silicon resin, and glass are preferably employed. As the dispersant, barium titanate, titanium oxide, aluminum oxide,

silicon dioxide and the like are preferably used. In addition to the dispersant, phosphor may also be contained in the molding material. Therefore, the phosphor may be contained either in the molding material or in the coating material and other part. Or otherwise, the coating may be of other materials such as a resin containing phosphor and the molding material may be glass. In this case, such a light emitting diode can be made that is suited to mass production and is less affected by moisture. The molding and the coating may also be made of the same material in consideration of the refractive index.

[0040]

(Display device)

When the light emitting diode of the present invention is used in a LED display, it provides display of white color of higher definition than a LED display device made by simply combining light emitting diodes which emit light of RGB colors. That is, in order to display white light by combining light emitting diodes and mixing light of different colors with the conventional display device, light emitting diodes of RGB colors must be illuminated at the same time. Thus the display area for each pixel becomes larger compared to the case of monochromatic display of red, green and blue colors. Therefore, high definition cannot be achieved when displaying with white light compared to the case of monochromatic display of RGB colors. Also because display with white light is achieved by controlling the emission power of the

individual light emitting diodes, temperature characteristics of the semiconductors must be taken into consideration. Moreover, because the display is produced by mixing different colors, the light emitting diodes of RGB colors may be partially blocked resulting in changing display color, depending on the direction and angle of view with respect to the LED display. The display device which employs the light emitting diode of the present invention instead of the light emitting diodes of RGB colors is capable of achieving display with higher definition, stable display of white light and reduce unevenness in color. The light emitting diode of the present invention can also be used together with the RGB light emitting diodes. This display device is capable of improving the luminance.

[0041]

A LED display employing the light emitting diode of the present invention will be described. In this LED display device one pixel is constituted of each of RGB light emitting diodes and one light emitting diode of white color and these light emitting diodes are arranged in optional construction such as signal or matrix construction. The LED display is electrically connected with a lighting circuit which is a drive circuit. By means of output pulses of the drive circuit, display device capable of displaying various images can be achieved. The drive circuit has a RAM (Random Access Memory) which is video data storage means for temporarily storing the input display data, a tone control circuit which

processes the data stored in the RAM to compute tone signals for lighting the light emitting diodes of the LED display device with specified brightness and a driver which is switched by the output signal of the tone control circuit to cause the light emitting diodes to illuminate. The tone control circuit computes the duration of lighting the light emitting diodes of the LED display from the data stored in the RAM, and outputs pulse signals for turning on and off the light emitting diodes. When displaying with white light, width of the pulse signals for lighting the RGB light emitting diodes is made shorter, or peak value of the pulse signal is made lower or no pulse signal is output at all. On the other hand, a pulse signal is given to the white light emitting diode in compensation thereof. This causes the LED display device to display with white light.

[0042]

Therefore, it is preferable that a CPU be provided separately as a tone control circuit which computes the pulse signal for lighting the white light emitting diode with specified brightness. The pulse signal which is output from the tone control circuit is given to the white light emitting diode driver thereby to switch the driver. The white light emitting diode illuminates when the driver is turned on, and goes out when the driver is turned off.

[0043]

Another LED display device employing the light emitting

diode of the present invention will be described. The LED display device employs only the light emitting diode of the present invention and is used in a black and white LED display. The black and white LED display has only the light emitting diode of the present invention arranged in matrix construction. It can drive the LED display by means of a drive circuit for white light emitting diode, instead of the plurality of drive circuits for RGB light emitting diodes. The LED display is electrically connected with a lighting circuit which is a drive circuit. By means of output pulses of the drive circuit, display device capable of displaying various images can be achieved. The drive circuit has a RAM (Random Access Memory) which is video data storage means for temporarily storing the input display data, a tone control circuit which processes the data stored in the RAM to compute tone signals for lighting the light emitting diodes of the LED display device with specified brightness and a driver which is switched by the output signal of the tone control circuit to cause the light emitting diodes to illuminate. The tone control circuit computes the duration of lighting the light emitting diodes of the LED display from the data stored in the RAM, and outputs pulse signals for turning on and off the light emitting diodes.

[0044]

Thus the black and white LED display is, unlike the full-color RGB display device, capable of simplifying the circuit construction and achieving high definition display. Therefore, it

can provide a display free from color unevenness due to the characteristics of the RGB light emitting diodes, at a lower cost. It also imposes less stimulation to the eye compared to the conventional LED display which employs only red and green colors, and is suited for use over a long period of time.

[0045]

(Traffic signal)

When the light emitting diode of the present invention is used as a traffic signal which is a kind of display device, such advantages can be obtained as stable illumination over a long period of time and no color unevenness even when part of the light emitting diodes go out. The traffic signal employing the light emitting diode of the present invention has such a configuration as white light emitting diodes are arranged on a substrate whereon a conductive pattern is formed. A circuit of light emitting diodes wherein such light emitting diodes are connected in series or parallel is handled as a set of light emitting diodes. Two or more sets of light emitting diodes are used, each having the light emitting diodes arranged in spiral configuration. When all light emitting diodes are arranged, they are arranged over the entire area in circular configuration. After connecting power lines by soldering for the connection of the light emitting diodes and the substrate with external power supply, it is secured in a chassis of railway signal. The LED display is placed in an aluminum diecast chassis equipped with a light blocking member and is sealed on the

surface with silicon rubber filler. The chassis is provided with a white color lens on the display plane thereof. Electric wiring of the LED display is passed through a rubber packing on the back of the chassis, with the inside of the chassis closed. Thus a signal of white light is made. A signal of higher reliability can be made by dividing the light emitting diodes of the present invention into a plurality of groups and arranging them in a spiral configuration swirling from a center toward outside, while connecting them in parallel. The configuration of swirling from the center toward outside may be either continuous or intermittent. Therefore, desired number of the light emitting diodes and desired number of the sets of light emitting diodes can be selected depending on the display area of the LED display device. This signal is, even when one of the sets of light emitting diodes or part of the light emitting diodes fail to illuminate due to some trouble, capable of illuminate evenly in a circular configuration by means of the remaining set of light emitting diodes or remaining light emitting diodes. Also it is free from color shift. Because the light emitting diodes are arranged in a spiral configuration, they can be arranged more densely near the center, and driven without any different impression from signals employing incandescent lamps.

[0046]

(Planar light source)

The light emitting diode of the present invention can also be used to make a planar light source as shown in Fig. 7. In

the planar light source, the phosphor is contained in a coating material and a diffuser sheet 706 provided on an optical guide plate. Or otherwise the phosphor may be applied onto the diffuser sheet 706 together with a binder resin to form into a sheet 701, while omitting the molding material. Specifically, the LED chip 702 is secured in a metal substrate 703 of inverted C shape whereon an insulation layer and a conductive pattern are formed. After electrically connecting the LED chip and the conductive pattern, phosphor is mixed with epoxy resin and applied onto the metal substrate 703 whereon the LED chip 702 is mounted. The LED chip thus secured is fixed onto an end face of an acrylic optical guide plate 704 by means of an epoxy resin or the like. A reflector film 707 containing a white diffusion agent is arranged on one of principal planes of the optical guide plate 704 for the purpose of preventing fluorescence. Similarly, a reflector 705 is provided on the entire surface on the back of the optical guide plate and on one end face where the LED chip is not provided, in order to improve the light emission efficiency. With this configuration, light emitting diodes can make a planar light source which generates enough luminance for the back light of LCD. Application to a liquid crystal display can be achieved by arranging a polarizer plate on the principal plane of the optical guide plate 704 via liquid crystal injected between glass substrates whereon a translucent conductive pattern not shown in the drawing is formed. Examples of the present invention will be described below. It should be understood that

the present invention is not limited to the Examples.

[0047]

[Examples]

(Example 1)

A GaInN semiconductor having an emission peak at 450 nm was used as a light emitting component. A LED chip was made by flowing TMG (trimethyl gallium) gas, TMI (trimethyl indium) gas, nitrogen gas and dopant gas together with a carrier gas on a cleaned sapphire substrate and forming a gallium nitride compound semiconductor layer in the MOCVD process. A gallium nitride semiconductor having N type conductivity and a gallium nitride semiconductor having P type conductivity are formed by switching SiH_4 and Cp_2Mg as dopant gas, thereby forming a PN junction. The P type semiconductor was annealed at a temperature of 400 °C or above after forming the film.

[0048]

After exposing the surfaces of P type and N type semiconductor layers by etching, electrodes were formed by sputtering. After scribing the semiconductor wafer which has been made as described above, LED chips were made as light emitting components by dividing the wafer with external force.

[0049]

The LED chip was mounted on a mount lead having a cup at the tip of a silver-plated copper lead frame, by die bonding with epoxy resin. Electrodes of the LED chip, the mount lead and

the inner lead were electrically connected by wire boding with gold wires.

[0050]

On the other hand, a phosphor was made by dissolving rare earth elements of Y, Gd and Ce in an acid in stoichiometrical proportions, and coprecipitating the solution with oxalic acid. Oxide of the coprecipitate obtained by firing this material was mixed with aluminum oxide and gallium oxide, thereby to obtain the mixture material. The mixture was then mixed with ammonium fluoride used as a flux, and fired in a crucible at a temperature of 1400 °C in air for 3 hours. Then the fired material was ground by a ball mill in water, washed, separated, dried and sieved thereby to obtained the desired material.

[0051]

80 Parts by weight of the fluorescent material having a composition of $(Y_{1.2}Gd_{0.8})_5Al_3O_{12}$:Ce which has been made and 100 parts by weight of epoxy resin were well mixed to turn into slurry. The slurry was poured into the cup provided on the mount lead whereon the LED chip was mounted. After pouring, the resin containing the phosphor was cured at 130 °C for one hour. Thus a coating 120 μm thick containing the phosphor was formed on the LED chip. Concentration of the phosphor in the coating was tapered to increase toward the LED chip. The LED chip and the phosphor were molded with translucent epoxy resin for the purpose of protection against extraneous stress, moisture and dust. A lead frame with the coating

layer of phosphor formed thereon was placed in a bullet-shaped die and mixed with translucent epoxy resin and then cured at 150 °C for 5 hours. Under visual observation of the light emitting diode formed as described above in the direction normal to the light emitting plane, it was found that the central portion was rendered yellowish color due to the body color of the phosphor.

[0052]

Measurements of chromaticity point, color temperature and color rendering index of the light emitting diode made as described above and capable of emitting white light gave values of (0.302, 0.280) for chromaticity point (x, y), color temperature of 8080K and 87.5 for Ra (color rendering index) which are approximate to the characteristics of a 3-waveform fluorescent lamp. Light emitting efficiency of 9.51 m/W comparable to that of an incandescent lamp. Further in life tests under conditions of energization with a current of 60 mA at 25 °C, 20 mA at 25 60 °C and 20 mA at 60 °C with 90% RH, no change due to the fluorescent material was observed, proving that the light emitting diode has no difference in service life from conventional blue light emitting diode.

[0053]

(Comparative Example 1)

According to the same manner as that described in Example 1 except for changing the phosphor from $(Y_{1.2}Gd_{0.8})Al_3O_{12}$:Ce to (ZnCd)S:Cu, Al, the formation of a light emitting diode and life

test thereof were conducted. The light emitting diode which had been formed showed, immediately after energization, emission of white light but with low luminance. In a life test, the output diminished to zero in about 100 hours. Analysis of the cause of deterioration showed that the fluorescent material was blackened.

[0054]

This trouble is supposed to have been caused as the light emitted by the light emitting component and moisture which was on the fluorescent material or entered from the outside brought about photolysis to make colloidal zinc to precipitate on the surface of the fluorescent material, leading to blackened surface. Results of life tests under conditions of energization with a current of 20mA at 25 °C and 20mA at 60 °C with 90% RH are shown in Fig. 8 together with the results of Example 1. Luminance is given in terms of relative value with respect to the initial value as the reference. A solid line indicates Example 1 and a wavy line indicates Comparative Example 1.

[0055]

(Example 2)

A LED chip having emission peak at 460 nm was made by increasing the content of In in the nitride compound semiconductor compared to that of Example 1. The phosphor was made according to the same manner as that described in Example 1 except for increasing the content of Gd than that of Example to have a composition of $(Y_{0.6}Gd_{0.4})Al_5O_{12}$:Ce. Thus 100 pieces of light emitting diodes were

made to conduct the life test.

[0056]

Measurements of chromaticity point, color temperature and color rendering index of the light emitting diodes capable of emitting white light, which were made as described above, gave values of (0.375, 0.370) for chromaticity point (x, y), color temperature of 4400K and 86.0 for Ra (color rendering index). Further in life tests, 100 light emitting diodes were averaged. Average luminous intensity was taken after 1000 hours in percentage of the luminous intensity value before the life test. The average luminous intensity after the life test was 98.8%, proving no difference in the characteristic.

[0057]

(Example 3)

100 light emitting diodes were made in the same manner as in Example 1 except for adding Sm in addition to rare earth elements Y, Gd and Ce in the phosphor to make a fluorescent material with the composition of $(Y_{0.39}Gd_{0.57}Ce_{0.03}Sm_{0.01})_3Al_5O_{12}$. When the light emitting diodes were made illuminate at a high temperature of 130 °C, average temperature characteristic about 8% better than that of Example 1 was obtained.

[0058]

(Example 4)

The light emitting diode of the present invention was used in one of LED display devices as shown in Fig. 5. The light

emitting diodes made according to the same manner as that described in Example 1 were arranged in a 16x16 matrix on a ceramics substrate whereon a copper pattern was formed. The light emitting diodes were soldered onto the substrate by means of an automatic soldering machine, and the assembly thus made was placed in a chassis 504 made of phenol resin and secured. A light blocking member 505 was formed integrally with the chassis. The chassis, the light emitting diodes, the substrate and part of the light blocking member, except for the tips of the light emitting diodes, were covered with silicon rubber 406 colored in black with a pigment. Then the silicon rubber was cured at the normal temperature for 72 hours, thereby to form the LED display device. The LED display device, a RAM (Random Access Memory) which temporarily stores the input display data, a tone control circuit which processes the data stored in the RAM to compute tone signals for lighting the light emitting diodes with specified brightness and CPU drive means which is switched by the output signal of the tone control circuit to cause the light emitting diodes to illuminate were electrically connected to make a LED display device. By driving the LED display devices, it was verified that the device can be used as black and white LED display device.

[0059]

[Effect of the invention]

According to the present invention, by combining light emitting component of nitride compound semiconductor and

$RE_3(Al,Ga)_5O_{12}$:Ce fluorescent material, a light emitting diode having a high emission efficiency even after operation with high luminance over a long period of time can be made. With high reliability, energy saving performance, compact construction and capability to change color temperature, the light emitting diode of the present invention can open up new applications as illumination in addition to display in automobile, aircraft and electric appliances in general. Also the light emitting diode of the present invention is better for the human eyes because white light imposes less stimulation to the eye when watched for a long period of time.

[0060]

The construction described in claim 1 of the present invention, in particular, makes it possible to obtain various light emitting diodes capable of emitting white light with high luminance, minimum color shift and minimum deterioration in light emission efficiency even when used over an extended period of time.

[0061]

The construction described in claim 2 of the present invention makes it possible to obtain various light emitting diodes having high luminance, minimum color shift and minimum deterioration in light emission efficiency even when used over an extended period of time. In addition, even when a plurality of light emitting diodes are mounted close to each other, erroneous illumination due to excitation of fluorescent material by light

from other light emitting diode mounted nearby can be prevented. Because unevenness in emission of the LED chip itself can be smoothed out by the fluorescent material, the light emitting diode can emit light uniformly.

[0062]

The construction described in claim 3 of the present invention makes it possible to obtain a light emitting diode having less temperature dependency.

[0063]

The construction described in claim 4 of the present invention makes it possible to make a relatively low-priced LED display device of high definition and a LED display device which shows less unevenness in color regardless of the angle of view.

[0064]

[Brief Description of the Drawings]

[Fig. 1] Fig. 1 is a schematic sectional view of the light emitting diode of the present invention.

[Fig. 2] Fig. 2 is a schematic sectional view of another light emitting diode of the present invention.

[Fig. 3] Fig. 3 shows one embodiment of emission spectrum of the light emitting diode of the present invention.

[Fig. 4] Fig. 4(A) shows one embodiment of absorption spectrum of the phosphor used in the present invention, and Fig. 4(B) shows one embodiment of emission spectrum of the phosphor used in the present invention.

[Fig. 5] Fig. 5 schematically shows the LED display device employing the light emitting diode of the present invention.

[Fig. 6] Fig. 6 is a block diagram of the LED display device of Fig. 5.

[Fig. 7] Fig. 7 schematically shows another LED display device employing the light emitting diode of the present invention.

[Fig. 8] Fig. 8(A) is a graph showing the results of the life test of the light emitting diodes of Example 1 and Comparative Example 1 under conditions of energization with a current of 20mA at 25°C and Fig. 8(B) is a graph showing the results of the life test of the light emitting diodes of Example 1 and Comparative Example 1 under conditions of energization with a current of 20mA at 60°C with 90% RH.

[Description of the Reference Numerals]

101, 701: Coating material wherein photoluminescence is contained

102, 202, 702: LED chip

103, 203: Conductive wire

104: Molding material

105: Mount lead

106: Inner lead

201: Molding material wherein photoluminescence is contained

204: Casing

205: Electrodes provided on casing

501: Light emitting diode

504: Chassis

505: Light blocking material

506: Filling material

703: Metallic substrate

704: Optical guide plate

705, 707: Reflective material

706: Diffusion sheet

Fig. 1

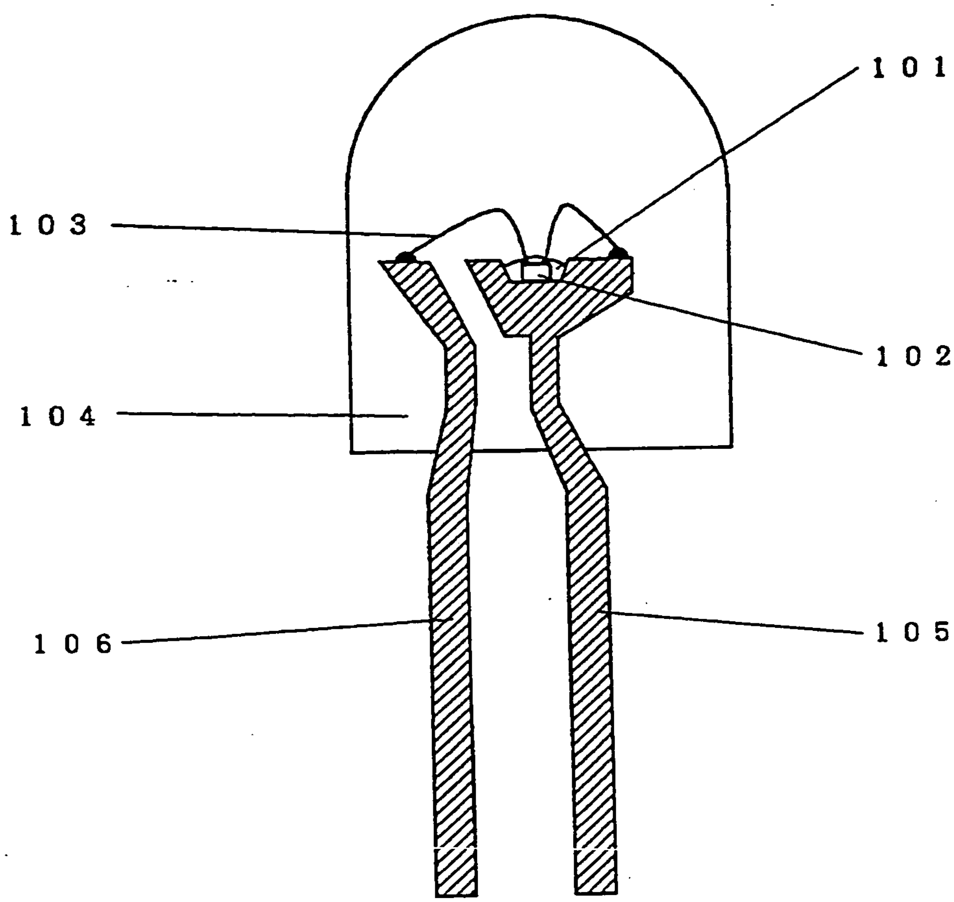


Fig. 2

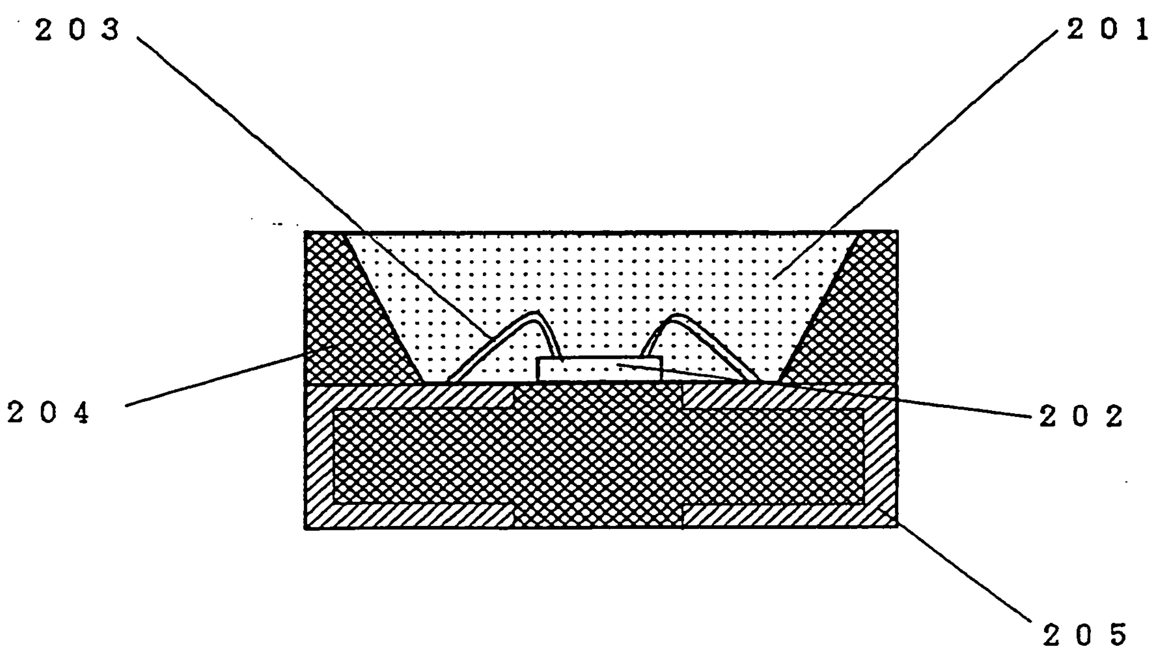


Fig. 3

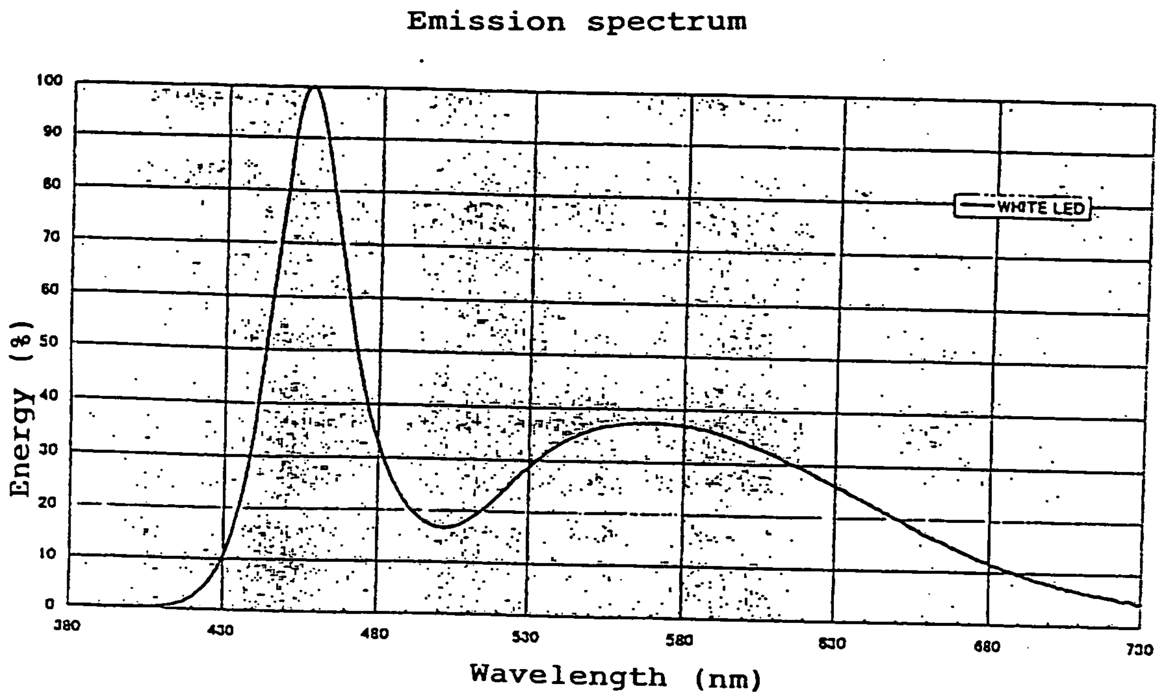
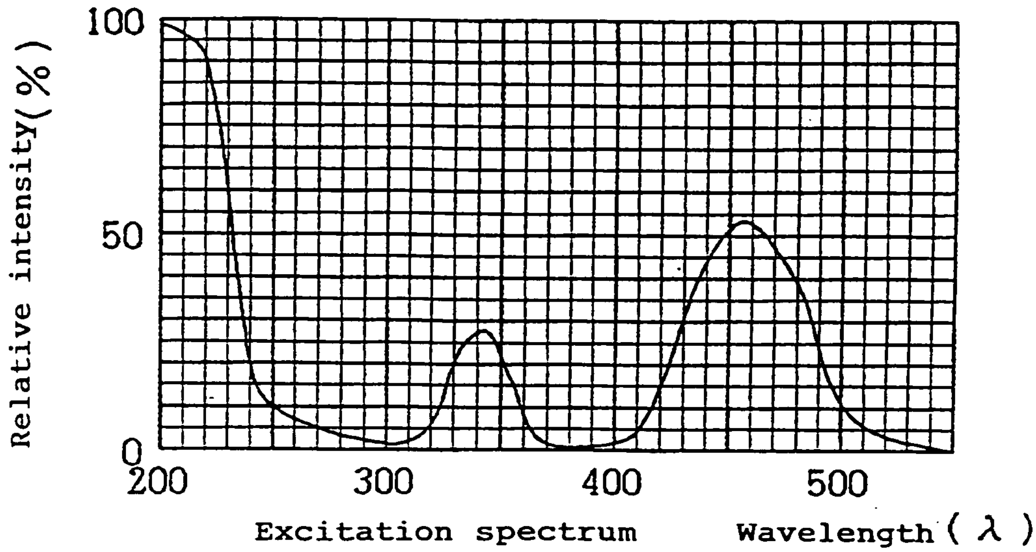
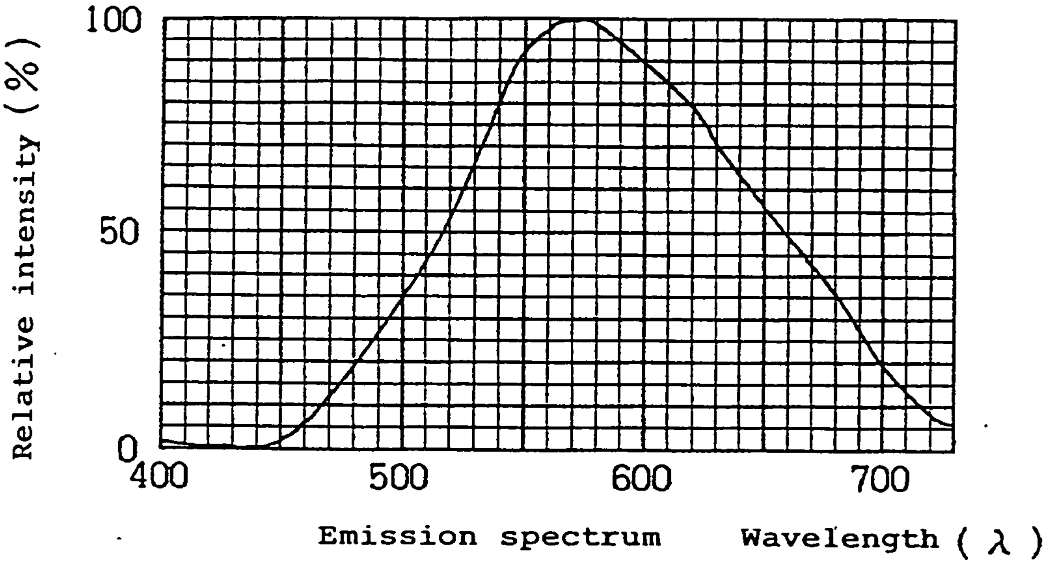

Emission spectrum
Energy (%)
100
90
80
70
60
50
40
30
20
10
0
380
430
480
530
580
630
680
730
Wavelength (nm)
WHITE LED

Fig. 4



Relative intensity(%)
100
50
0
200
300
400
500
Excitation spectrum
Wavelength (λ)

(A)



Relative intensity (%)
100
50
0
400
500
600
700
Emission spectrum
Wavelength (λ)

(B)

Fig. 5

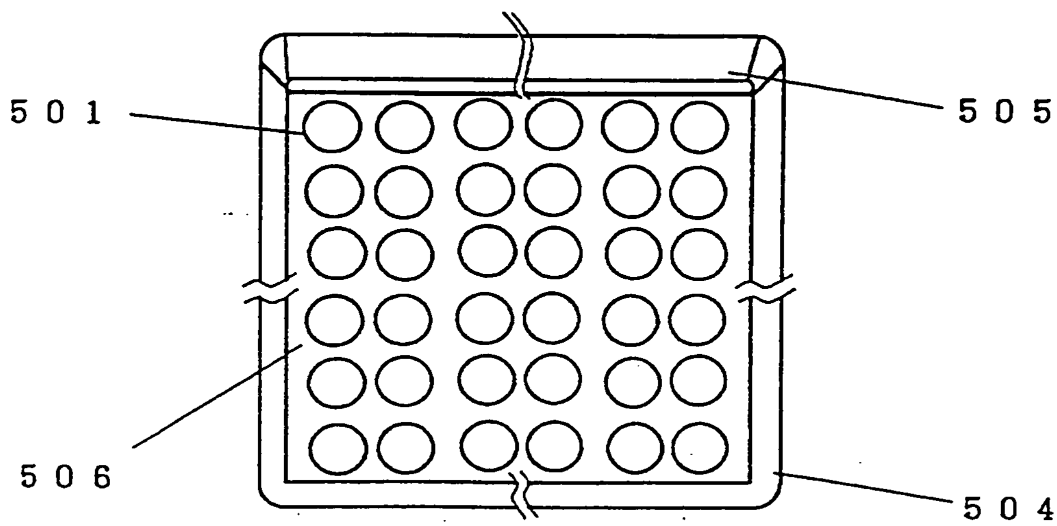


Fig. 6

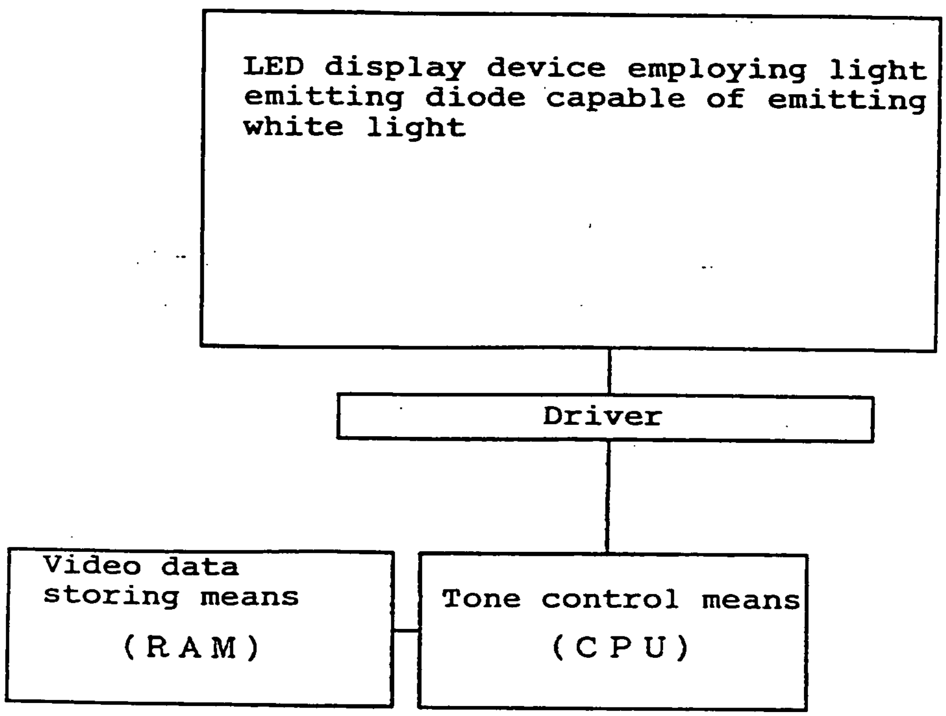

LED display device employing light emitting diode capable of emitting white light
Driver
Video data storing means
(RAM)
Tone control means
(CPU)

Fig. 7

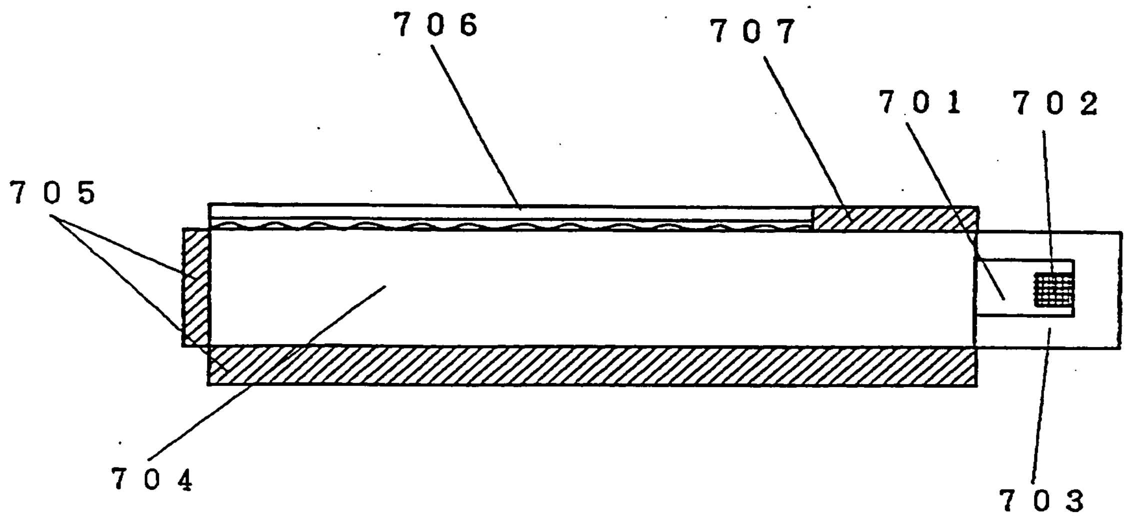
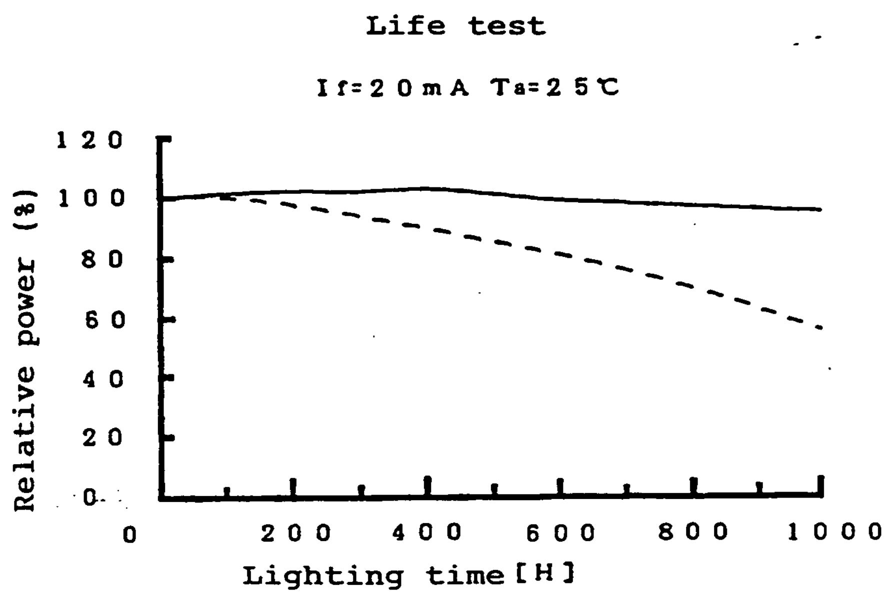
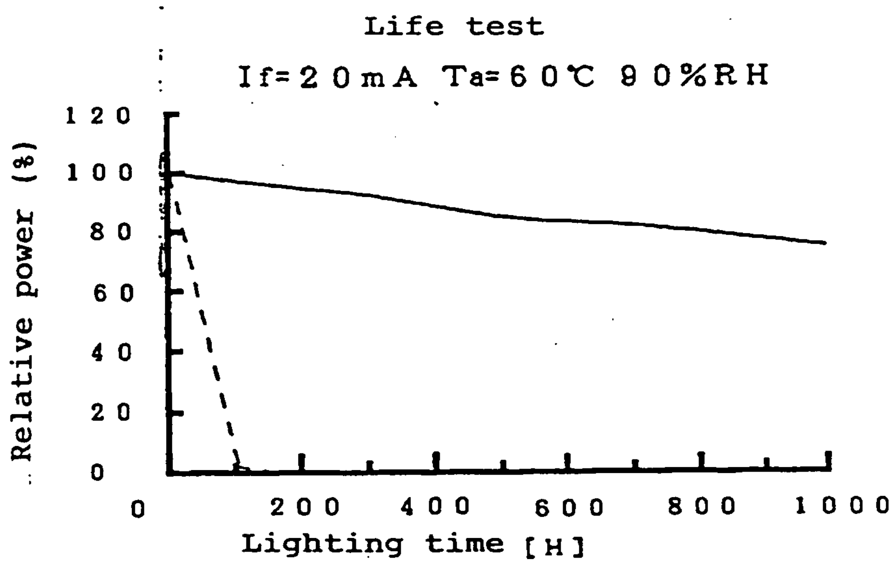


Fig. 8



Life test
If=20mA Ta=25℃
120
100
80
60
40
20
0
Relative power (%)
0
200
400
600
800
1000
Lighting time [H]

(A)



Life test
If=20mA Ta=60℃ 90%RH
120
100
80
60
40
20
0
Relative power (%)
0
200
400
600
800
1000
Lighting time [H]

(B)

[Document Name] Abstract

[Abstract]

[Object] It is to provide a light emitting diode having a phosphor, which converts light emitted by a LED chip and emits light, and providing high luminance and high efficiency regardless of the operating environment, and a display device using the same.

[Means for solving] The light emitting diode has a LED chip using a gallium nitride compound semiconductor as a light emitting layer and a phosphor which absorbs at least a part of light emitted by the LED chip to emit light by converting the wavelength. A main peak of the emission spectrum of the LED chip has an emission wavelength within the range from 400nm to 530nm and the phosphor is represented by $RE_3(Al,Ga)_5O_{12}$:Ce, where RE is at least one selected from Y, Gd and Sm.

[Selected drawing] Fig. 1

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Corrected Document: Petition for Patent

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Address: 491-100, Oka, Kaminakacho, Anan-shi, Tokushima, Japan
Name: Nichia Chemical Industries, Ltd.

Applicant Record

Identification No.: [000226057]

1. Date of Registration: August 18, 1990 (newly recorded)

   Address: 491-100, Oka, Kaminakacho, Anan-shi, Tokushima, Japan
   Name: Nichia Chemical Industries, Ltd.